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One color contrast enhanced infrared and visible image fusion method

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ABSTRACT

Color constancy (Toet and Franken, 2003 [2]; Toet, 2003 [7]) and color contrast (Scribner et al., 2000 [21]; Lee et al., 2005 [23]) are two important topics for color image fusion. The paper focuses on the low color contrast problem of linear fusion algorithms with color transfer method. Color transfer technology is popular in infrared (IR) and visible image fusion to give the fused image a natural day-time color appearance (Toet, 2003 [7]; Wang et al., 2007 [8]; Zheng and Essock, 2008 [9]). However, in the color transfer step, all three channels of the color space are processed with the same linear mapping without color enhancement, resulting in low color contrast between the target and the background (Wang et al., 2007 [8]). Based on the characteristics of the IR image, we introduce a ratio of local to global divergence of the IR image to improve the color contrast. The enhancement ratios for both hot and cold targets are larger than one, while it tends to one for the background. As a result, the proposed method pops out both hot and cold targets in color, where hot targets will appear intense red, and cold targets will appear cyan. Subjective results show visible color contrast enhancement effects. Target detection experiments through hue and saturation components of the fused image show an improvement in the hit rate for target detection, owing to larger color distance between the target and the background.

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1. Introduction

As two of the most commonly used image sensors in night-vision for military applications, infrared (IR) and visible light cameras have their own advantages and limitations due to the physical differences between the image formation processes. The IR image records thermal radiations emitted by objects in a scene and can be utilized to discover targets as it has better hot contrast and can present camouflaged targets. The visible image has much more high-frequency information of the background, which is essential to accurate target localization and situation awareness [1,2]. Thus, appropriate fusion of IR and visible images can combine the complementary information and obtain a better description of the scene, which will help in target detection, target localization and situation awareness tasks [1–4].

Color acts as a basic factor in the human visual system. Perceptual evaluation practices show that appropriately color fused night-vision imagery is often helpful for human observers to improve their performance, for instance, on situation awareness, target detection, search and classification [1–4]. In recent years, color image fusion is becoming a more and more important research field and lots of novel false color fusion approaches have been developed to fuse IR and visible images [5,6].

One key topic of the color fused imagery is color constancy. It has been shown that the lack of color constancy with inappropriate color mapping may hinder human performance [2]. In 2003, Toet originally introduced the color transfer technology to produce night-vision imagery with a natural appearance and with colors that are to some extent invariant for changes in the environmental conditions [7]. By transferring the mean and standard deviation of a selected natural day-time color imagery to the false color fused image for each channel in an appropriate color space, the approach can be used effectively to give multi-band night-vision imagery a natural day-time color appearance. Further more, it has been experimentally demonstrated that the false color fused image and the selected reference image do not have to be of the same scene [7–9]. Satisfactory results can be obtained so long as they are similar to each other to some degree, which extends applications of the approach greatly.

Another key topic of the color fused imagery is color contrast, which enhances human visual capabilities in discriminating features from their background and is essential to target detection tasks [21,23]. However, to date, little attention has been paid to the color contrast problem while implementing color transfer. In the color transfer step, all three channels of the color space are processed with the same linear mapping without color contrast enhancement [7]. As a result, targets that are clear in the IR image

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may have the similar color to the background in the fused image and are difficult to detect [8]. In [9], Yufeng Zheng et al. proposed a novel local algorithm based on image segmentation, recognition and local color transfer to enhance the color mapping effect. However, the color image segmentation and recognition are both time-consuming and inclined to make mistakes (85% of accuracy was reported). In this paper, we address the topic of color contrast and present a color contrast enhanced image fusion method to give boost to color of targets.

2. Linear image fusion

The schematic diagram of linear image fusion is shown in Fig. 1. The source IR and visible images are firstly fused by false color fusion and then the color transfer technology is applied to obtain a natural final fused image.

Different false color fusion approaches and different color spaces can be utilized in the scheme [7–9]. In this paper, we implement the false color fusion and color transfer step in YUV space, where Y denotes luminance, U stands for difference between blue and luminance, and V stands for difference between red and luminance. The transform from RGB space to YUV space is written as:

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.1471 & -0.2888 & 0.4359 \\ 0.6148 & -0.5148 & -0.1000 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}. \tag{1}$$

The false color fusion in YUV space is carried out as:

$$\begin{cases} Y_C = \text{Vis}, \\ U_C = \text{Vis}-\text{IR}, \\ V_C = \text{IR}-\text{Vis}, \end{cases} \tag{2}$$

where Vis and IR stand for the visible image and the IR image, respectively. By mapping the visible image to the achromatic channel, the high-frequency information of the visible image is kept in the fused image. The differencing operation between the visible and the IR image provides intersensor contrast, which in a general sense is similar to the spatial center/surround color opponency shown in the primate visual system [10]. As a result, the chromatic channels of the fused image show intersensor contrast, making popping targets in color possible. For the IR image, elements that are hotter (the human body for example) or colder (vehicles that keep still for example) than their background are deemed to be possible targets [11]. For the false color fusion approach adopted, as V is the difference between red and luminance, hot targets will appear reddish. For cold targets, the green and blue channels will dominate in the final fused image, leading to the cyan color.

In the following step, color transfer is implemented to make the final fused image and the reference image have the same mean and standard deviation for each channel in an appropriate color space. The color transfer technology is based on the fact that straightforward color statistics can capture some important subjective notions of style and appearance in images [12]. In YUV color space, the color transfer step can be written as:

$$P_F = \frac{\sigma_R^P}{\sigma_C^P}(P_C - \mu_C^P) + \mu_R^P, \quad P = Y,\ U,\ V, \tag{3}$$

where the indexes C, R and F refer to the false color fused image, the reference image and the final fused image, respectively. P denotes an individual color channel of the image in YUV space. μ and σ refer to the mean and standard deviation of channel P, respectively. By applying a linear mapping to each channel of the false color fused image as in Eq. (3), the final fused image will take the style and appearance of the reference image.

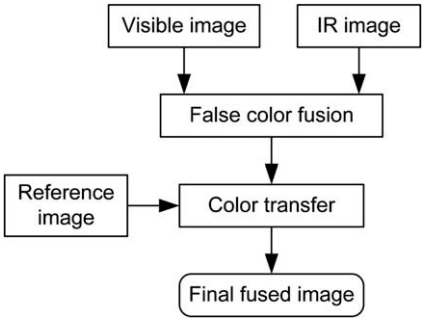

Fig. 1. Schematic diagram of linear image fusion.

3. Color contrast enhancement in IR and visible image fusion

While the advantage of image fusion for situation awareness tasks has been well demonstrated [2,3], its effect on target detection is still ambiguous as the detection mainly depends on contrast between the target and the background, which is usually high in the IR image [2–4]. Thus, ideal image fusion should maintain or improve the high detectability of the target in the IR image, while improving the situation awareness performance.

Owing to the human visual system, however, the resolution ability to the intensity of a color image is worse than that of a gray image. Consequently, a higher hit rate for target detection can not be achieved by using only intensity information in the color image-fusion scheme. Fortunately, color contrast provides another cue in the color fused image, which makes the separation between the target and the background easier. It has been demonstrated that the human ability to detect small objects against a varied background can be greatly facilitated by the use of color and fewer fixations are required to locate the target [13,14]. Further more, with large color contrast, the human performs a parallel target detection, while with low color contrast, response time increases with display density, indicating a serial search [15]. So, the color image fusion should pop out targets in color to improve their detectability.

In the linear image-fusion scheme, the relationship between targets and colors is similar to that of color-coded images, i.e. the fused images are partially color-coded, which will help to enhance targets [16,17]. However, the color information of targets has not been utilized enough as no special method is taken to enhance its color contrast. As a result, targets may have the similar color to the background in the fused image and are difficult to detect.

The main reason for low color contrast of the linear image-fusion scheme lies in that all three channels are processed with the same linear mapping in the color transfer step. To enhance the color contrast between the target and the background, we propose to enhance the V channel by a color contrast enhancement ratio η:

$$\begin{cases} P_F = \frac{\sigma_R^P}{\sigma_C^P}(P_C - \mu_C^P) + \mu_R^P, \quad P = Y, U, \\ V_F = \eta \bullet \frac{\sigma_R^V}{\sigma_C^V}(V_C - \mu_C^V) + \mu_R^V, \\ \eta = D/\mu_D, \\ D = |IR - \mu_{IR}|, \end{cases} \tag{4}$$

where D is the divergence of the intensity of each pixel from the mean intensity of the IR image, and η is the ratio of local to global divergence of the IR image. A 3×3 window can be used to get the local mean divergence to eliminate noise in the IR image.

As both hot and cold targets are of great divergences from the mean intensity of the IR image, both of them can be enhanced. With color contrast enhancement, hot targets will appear intense red, while cold targets will appear cyan in the fused image. The

red color of hot targets can alert observers of possible danger, and the cyan color can help observers to detect cold targets or low-temperature regions (if there are no cold targets).

4. Fusion results

To validate the effectiveness of our method, three image sets called *uncamp*, *trees* and *dune* are fused. For comparison, we also obtain the color fused images by linear image fusion without enhancement and by Wang's [8] enhancement method. Three pairs of them are completely analyzed and shown in Figs. 2–4 (namely, NV1816, NV4917 and NV7404). Subjective results show visible color contrast enhancement between the target and the background in the final fused image.

For the NV1816 pair shown in Fig. 2, the man is the hot target, and the top region of the house is a cold target in the IR image. A natural day-time color image shown in Fig. 2c is selected as the reference image. As analyzed in Section 2, the man and the dark region should appear red and cyan respectively in the fused image. In Fig. 2d, however, without color contrast enhancement, the man takes on almost the same color as the background and is very difficult to detect. Wang's enhancement method gives considerable boost to color of the hot target as shown in Fig. 2e. However, little temperature information of the cold region is provided through color. By the proposed method, the man appears intense red and the cold target appears deep cyan, which is in accordance with previous analysis in Section 3 and can pop out both targets. At the same time, details of the background are well kept as can be seen in Fig. 2f.

The same conclusion can be deduced from experiments using NV4917 and NV7404 pairs. As we can see in Figs. 3 and 4d, without enhancement the man is hard to distinguish from the background. Wang's method provides a better result as the human appears red, despite part of it is still covered by the green color. The man in the fused image by our method is intense red in color. Further more, places where the intensities of the IR image are much lower than

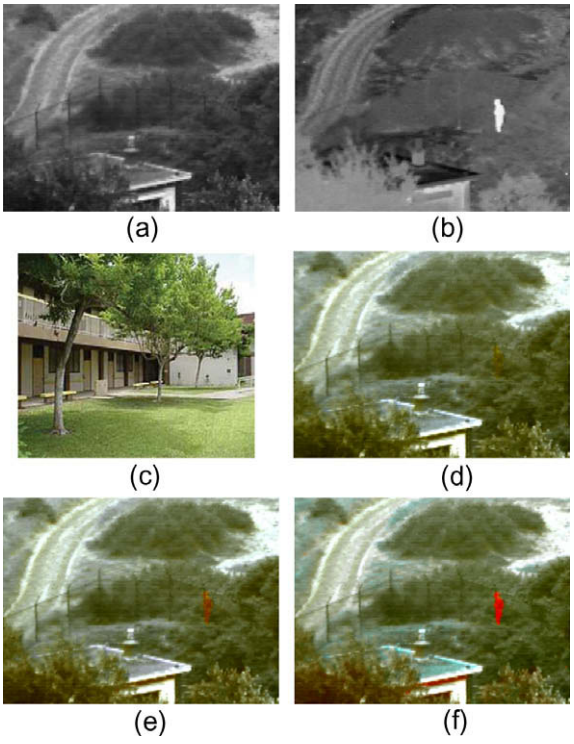

Fig. 2. IR and visible image fusion of image pair NV1816: (a) visible image; (b) IR image; (c) reference image; (d) result without enhancement; (e) result by Wang's method; (f) result by our method.

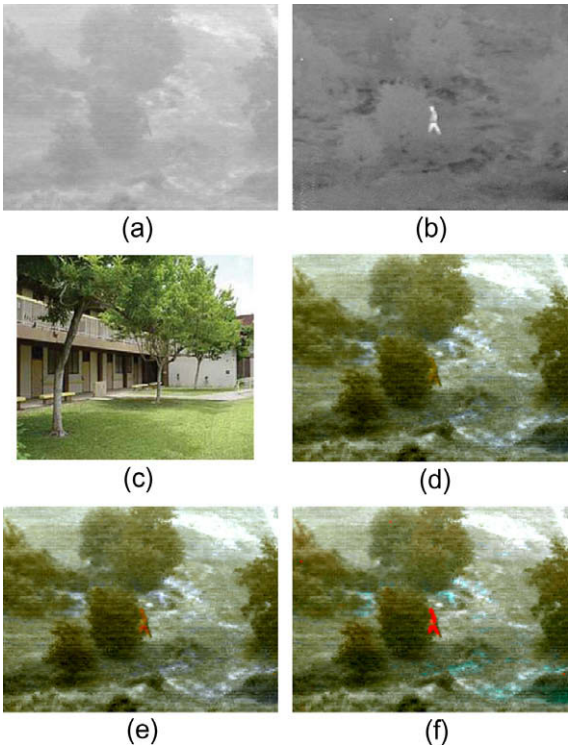

Fig. 3. IR and visible image fusion of image pair NV4917: (a) visible image; (b) IR image; (c) reference image; (d) result without enhancement; (e) result by Wang's method; (f) result by our method.

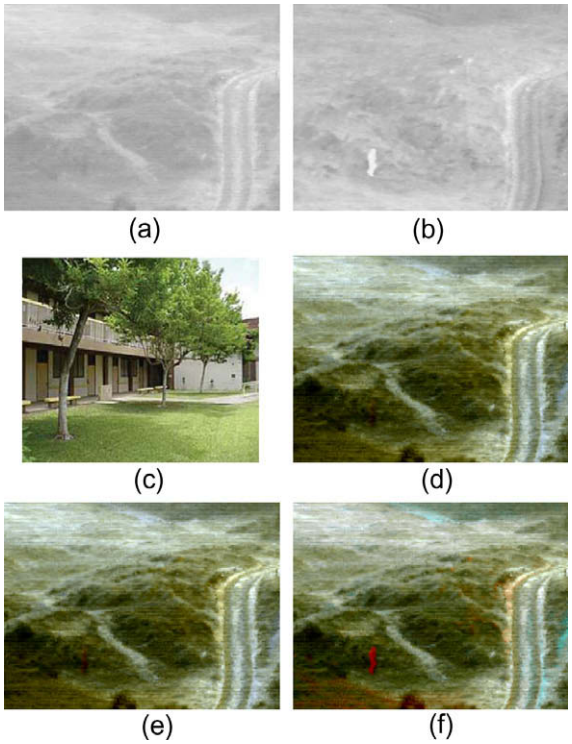

Fig. 4. IR and visible image fusion of image pair NV7404: (a) visible image; (b) IR image; (c) reference image; (d) result without enhancement; (e) result by Wang's method; (f) result by our method.

the background take on cyan, which will help judge the temperature distribution of the scene, though there is no cold target.

5. Discussion

Human visual inspection will be a good choice to evaluate fused images as it is in accordance with the application of image fusion. However, the reproduction of subjective tests is often time-consuming and difficult, while the exact same conditions for the test can not be guaranteed. Researchers tend to evaluate fused images with metrics and several well-accepted evaluation metrics for gray image fusion have been proposed [18–20]. Unfortunately, to the best of our knowledge, there is no effective and well-accepted objective metric for color fusion schemes. However, as we aim at improving the detectability of the target by enhancing color contrast between the target and the background, we can roughly evaluate different methods through their abilities of target-background separation [21]. As a result, we first measure the improvement in target detection by thresholding the color fused image through hue and saturation components [6,21] and obtaining a receiver-operator-characteristic (ROC) curve, which is a plot of false alarm rate versus detection rate. Then we measure the area-to-area [22] color distances between the target and the background for different fusion methods.

To obtain ROC curves, one precondition is to know the ideal target detection result, which is obtained manually in this paper. Take the NV1816 pair for example, we firstly segment the image into three regions as shown in Fig. 5, where the indexes H, B and C stand for the hot target, the background and the cold target, respectively.

According to the fact that color is perceived as intensity, hue and saturation by the human visual system, we perform target detection through the hue and saturation components in the chromatic plane of the fused image:

$$g(x,y) = \begin{cases} 1, & |H(x,y) - H_0| \le H_{Th} \text{and } |S(x,y) - S_0| \leqslant S_{Th}, \\ 0, & \text{otherwise}, \end{cases} \quad (5)$$

where $H(x,y)$ and $S(x,y)$ are the hue and saturation components of the fused image at the coordinate (x,y), respectively; H_0 and S_0 are the mean of the hue and saturation of the target, respectively; H_{Th} and S_{Th} are some given hue and saturation thresholds; and $g(x,y)$ is the target detection result. The ROC curves are obtained with varying hue and saturation thresholds for the target detection, as shown in Fig. 6.

From Fig. 6, it can be easily seen that the proposed method provides an improvement for both the hot and the cold target detection, as for the same false alarm rate, it obtains a higher detection rate. Wang's method provides a modest performance improvement for the hot target detection. However, for the cold target detection, the performance by Wang's method is not as good as that of the general fusion scheme without enhancement.

The hit rate of color vision in detecting a target relies mainly on its ability to characterize color [23]. When the target is very close to the background in color, it results in a growth of false alarm rate. The effect of color contrast enhancement can be illustrated by comparing area-to-area color distances between the target region and the background for different fusion methods. As HSV color space is nonuniform, we still measure the color distance in YUV space:

$$D_{T-B} = \sqrt{(Y_T - Y_B)^2 + (U_T - U_B)^2 + (V_T - V_B)^2}, \quad (6)$$

where the indexes T and B stand for the target and the background region, respectively.

Table 1 shows the comparison of color distances in YUV space for different methods. Wang's method enlarges the distance between the hot target and the background moderately, while the distance provided by our method is more than twice that of the general fusion scheme without enhancement. Besides, our method enlarges the color distance between the cold target and the background, resulting in a performance improvement demonstrated by the ROC curves for the cold target detection.

The effectiveness of the proposed method can be further explained through the enhancement ratios for each region. The mean enhancement ratios for all three regions by Wang's and our method are listed in Table 2. Both methods have the good property that they keep the background well as the mean enhancement ratios for

Fig. 5. Segmentation of image pair NV1816.

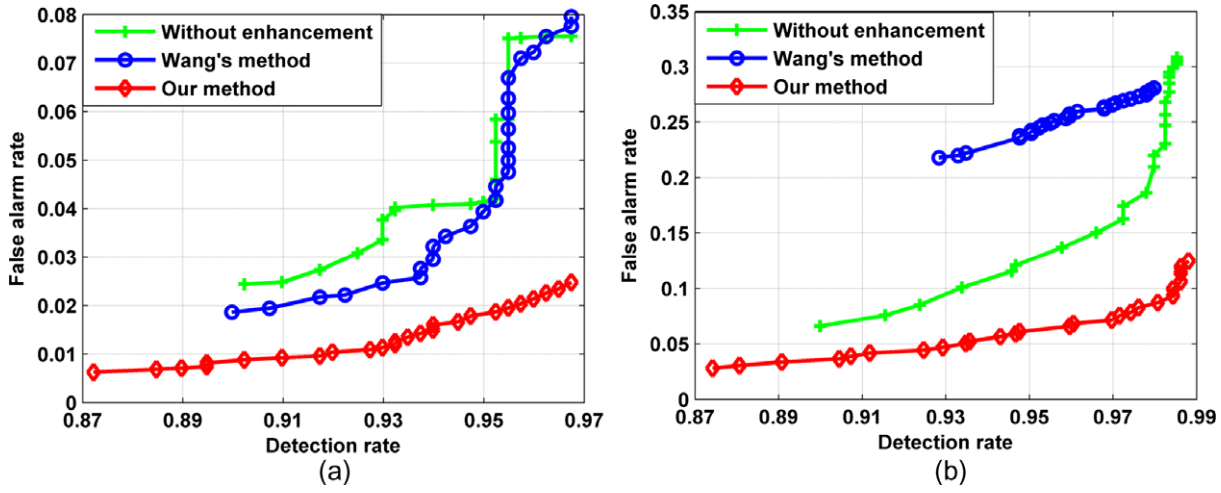

Fig. 6. ROC curves for the target detection with different image fusion methods: (a) ROC curves for the hot target detection; (b) ROC curves for the cold target detection.

Table 1
Comparison of color distances in YUV space for different fusion methods.

Color distance	Without enhancement	Wang's method	Our method
D_{H-B}	49.5	60.3	113.7
D_{C-B}	46.5	45.6	54.8

Table 2
The enhancement ratios for all three regions.

Region	Wang's method	Our method
H	2.34	5.87
C	0.33	2.95
B	1.01	0.96

the background tend to one. And for both methods, the mean enhancement ratios for the hot target region are larger than one, indicating that the hot target can be enhanced. However, as the enhancement ratio by our method is larger than that of Wang's method, the proposed method can provide a better enhancement result. The mean enhancement ratio for the cold target by Wang's method is much smaller than one, indicating that the cold target will be weakened in the fused image. In contrary, our method enhances the cold target effectively as the mean enhancement ratio for the cold target region is much larger than one.

6. Conclusion

An improved color image-fusion scheme is presented by introducing a color contrast enhancement approach, which gives boost to color of both hot and cold targets in the final fused image. Color contrast is effectively enhanced in our IR and visible image-fusion scheme, where hot targets will appear intense red and cold targets will appear cyan. The special relationship between targets and colors in the fused image offers more temperature information to the observer, which can aid target detection and improve observer performance. The proposed color contrast enhancement ratio is in accordance with the characteristics of the target and the background in IR images. The enhancement ratios for both hot and cold targets are larger than one, while it tends to one for the background. Thus both hot and cold targets can be enhanced, while details of the background are well kept by the proposed method, indicating the method is suitable for both target detection and situation awareness tasks.

The method is efficient in implementation. With a Pentium(R) 4 CPU of 2.8G Hz and 512 M RAM, experiments are carried out with Matlab 7.0. For the *uncamp* set tested, 3.1 s is spent to complete the fusion of all 32 pair of images with the resolution 360×270. That is to say, 10 frames per second can be achieved with modest requirement, indicating that real time implementation can be expected with appropriate hardware design.

The proposed color contrast enhancement approach can be further generalized in image-fusion schemes that utilize other color space. For example, Toet's fusion algorithm in $l\alpha\beta$ color space [7] can be improved by enhancing α channel using the enhancement ratio proposed in this paper. Further more, better visual results may be obtained when combined with local algorithms such as in [9].

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